PB84-211036

One Mgd Ion Exchange Plant for Removal of Nitrate from Well Water

(U.S.) Municipal Environmental Research Lab.
Cincinnati, OH

Jun 84

U.S. Department of Commerce
National Technical Information Service
NTIS

EPA-600/D-84-172
June 1984

A ONE MGD ION EXCHANGE PLANT FOR REMOVAL OF NITRATE FROM WELL WATER

PB84-211036

Richard P. Lauch
Research Sanitary Engineer
U.S. Environmental Protection Agency
Municipal Environmental Research Laboratory
Drinking Water Research Division
Cincinnati, Ohio 45268

Gerald A. Guter
Director of Environmental Studies
Boyle Engineering Corporation
Bakersfield, California 93302

Drinking Water Research Division
Municipal Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/D-84-172		PB84 211036

4. TITLE AND SUBTITLE	5. REPORT DATE
A One Mgd Ion Exchange Plant for Removal of Nitrate from Well Water	June 1984
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Richard P. Lauch and Gerald A. Guter	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
U.S. EPA, MERL, DWRD Cincinnati, Ohio 45268	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
U.S. EPA, MERL, DWRD Cincinnati, OH 45268	14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Richard Lauch 513/684-7467

16. ABSTRACT

A full scale 1 mgd demonstration plant, using ion exchange, for removal of nitrate from well water was built at McFarland, California. The plant has been performing satisfactorily in the semi-automatic mode since October 1983. Full automation of the plant was completed in June 1984. State of California requirements of reducing nitrate levels below 10 mg/L NO_3-N and eliminating brine from the product water have been met. Total costs for the plant, including capital and operation and maintenance were 24.2 cents/1000 gal. Research is continuing at McFarland on nitrate selective resins, regenerant re-use, monitoring and brine disposal, in an effort to further improve the process and reduce costs.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release to Public	Unclassified	25
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	

EPA Form 2220-1 (9-73)

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

A ONE MGD ION EXCHANGE PLANT FOR REMOVAL OF NITRATE FROM WELL WATER

Richard P. Lauch
Research Sanitary Engineer
U.S. Environmental Protection Agency
Municipal Environmental Research Laboratory
Drinking Water Research Division
Cincinnati, Ohio 45268

Gerald A. Guter
Director of Environmental Studies
Boyle Engineering Corporation
Bakersfield, California 93302

INTRODUCTION

Reason for Plant

A one mgd ion exchange plant was completed in October 1983 by the McFarland Mutual Water Company, McFarland, California to remove nitrate from their drinking water. McFarland is located in the southern part of the San Joaquin Valley (see Fig. 1) and has a population of approximately 6,000 people. The area is extensively agricultural and nitrate in the well water is caused by nitrogen fertilizers. McFarland's only water source at present is groundwater. Table 1 gives a water analysis for McFarland's four wells and shows that three of the four wells exceed the U.S. EPA regulation[1] of 10 mg/L for nitrate-nitrogen. McFarland has been using two wells (nos. 1 and 4) with a total capacity of 1400 gpm. Use of well no. 3 has been discontinued for public use because of high nitrate levels. McFarland has completed the nitrate removal plant at well no. 2 and they have also constructed two new deeper (>900 ft) wells to serve the developing areas. The trend for many San Joaquin valley communities shows that nitrate concentrations are gradually increasing, even in deeper wells, and this, along with the fact that capital costs for a deep well and a 1 mgd ion exchange plant at this location are about equal, is the reason that McFarland decided to build the nitrate removal plant. A progress report on the plant was given at the 1983 AWWA Seminar on Control of Inorganic Contaminants.[2]

The major contractor for McFarland's Plant was the Boyle Engineering Corporation of Bakersfield, California. Funds for the plant were furnished by the U.S. Department of Housing and Urban Development through the Kern County Community Development Program Department, by the Kern County Water Agency and by the McFarland Mutual Water Company. The U.S. EPA has also funded a cooperative agreement with the McFarland Mutual Water Co. (September 1981) to obtain cost and performance information on the new plant and to perform additional research on special nitrate selective resins and on improving the regeneration process.

Initial Research

Initial research at McFarland started in June 1978 under a cooperative agreement with the U.S. EPA, Drinking Water Research Division, Cincinnati, Ohio. Boyle Engineering Corporation was contracted by the McFarland Mutual Water Company under the agreement to perform the research. The objective of the initial study was to perform research

and pilot plant work to compare ion exchange, reverse osmosis (R.O.) and R.O. followed by ion exchange in series, to determine which process would be the most practical and economical for nitrate removal. The initial study[3] ended in June 1981 and one of the investigator's conclusions was: "the ion exchange process is generally more suitable as a well site treatment for nitrate removal than R.O. or a combination of the two. Ion exchange requires lower first and annual operating costs, has greater reliability, uses less energy, requires no additional well site storage, has higher water recovery, produces a more concentrated waste brine, and requires fewer automatic and electrical controls. Ion exchange can be operated on demand as required by distribution system needs. Such on-off operation is severely detrimental to an R.O. system which operates best on a continuous basis, hence, requires additional storage and repressurization. Brine disposal is a cost common to both processes." Estimated total costs (capital + O&M) from the initial study were $ 0.18/1000 gal for ion exchange vs. $1.00/1000 gal for R.O.

Additional research that was performed under the initial agreement resulted in the development of a selective anion exchange resin that prefers nitrate over sulfate and regenerant salt reduction through partial regeneration.

PLANT DESIGN

Basic Design

Figure 2 shows photographs of the plant. A simplified schematic of the plant is shown in Figure 3. The ion exchange plant was located between the existing well pump and the existing pressurized holding tank. The well pump is cycled by a pressure signal from the pressurized tank and, therefore, the water is treated as needed by the community. The plant is designed to treat a full one mgd, but normal operation will be to treat part of the water and blend so that the total well production is one mgd with a nitrate concentration that is below 10 mg/L NO_3-N.

The plant consists of three reaction vessels that are six feet in diameter and ten feet high. Each vessel was designed to contain either a 3 ft or 5 ft bed depth of anion exchange resin. Initially each vessel was charged with 3 ft of Duolite A-101-D* anion exchange resin. The three vessels were designed to operate in staggered fashion as shown in Figure 4. For example, when one freshly regenerated vessel starts its service mode, another vessel will be half exhausted, and the third vessel will start regeneration. Hence, two vessels are always in the service mode and the third vessel is in the regeneration or standby mode. Table 2 gives the bed characteristics, target flows, and presents operating conditions for a 3 ft bed depth. At the present time the plant is treating 500 gpm and blending with 200 gpm to give a total product flow of 700 gpm. Therefore, each vessel is treating 250 gpm and the empty bed contact time for each vessel is 2.54 minutes. Table 3 shows the number of regenerations per vessel per day for different operational conditions. Presently the plant is treating approximately 70% of the total water flow and, therefore, each vessel is regenerated 1.47 times per day when the plant runs continuously. There are times when the plant will turn off because of low water demand such as during the early morning hours.

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Plant Control

The plant is controlled by a model TI-500 microprocessor, manufactured by the Texas Instruments Corporation. The microprocessor receives a totalized flow signal from each vessel and automatically cycles the vessels as shown in Figure 4. The cycle will be interrupted when the main pump turns off because of low water demand from the community, but the system will resume automatically when the demand for water resumes. The microprocessor also receives signals of product water nitrate concentration and conductivity and automatically shuts off the system if nitrate-N is greater than 10 mg/L or conductivity is greater than influent conductivity. A periodic print out of these readings is also given. An operator is only required to check the plant once a day when the system is operating automatically.

Plant Size

The plant was designed so that the three vessels can operate with either three ft. or five ft. of resin. Both bed depths will be tried at McFarland and if a three ft. depth is satisfactory, then smaller vessels can be used for future plants. The inlet brine distributor (shown attached to pipe no. 1 Figure 5) can be rotated 180° to accommodate either bed depth of resin. Advantages of a three ft. bed depth are lower initial costs because the vessels would be smaller (6 ft. high instead of 10 ft.) and a smaller charge of resin would be used. Advantages of a five ft. bed depth are longer service periods between regenerations, extra capacity for the remaining two vessels if one vessel is taken off line for repair and longer resin life because of less frequent regeneration. The initial pilot plant study confirmed that a three ft. bed depth will give sufficient contact time for the exchange reaction to take place and increased pressure drop across a five ft. bed depth would be less than three psi which is insignificant.

Brine Disposal

Brine is disposed to the municipal waste treatment plant that consists of three aeration lagoons with effluent discharged to 128 acres of agricultural land that is used to grow animal feed crops and cotton. State approval for discharging the brine to the municipal plant has been given for the present. Municipal wastewater, soil, and groundwater samples, taken before and after the ion-exchange plant went on line, will be compared to determine if another disposal method such as a lined evaporation pond will be necessary.

State Health Requirements

An operating permit for the McFarland plant was issued by the California State Division of Health on May 13, 1983. Prior to issuance of the permit, a design review was conducted and the major requirements were:

1. Isolate brine from the product water with a double check valve.
2. Isolate wash water from the product water with block and bleed valves.
3. Keep nitrate levels in the product water below 10 mg/L NO_3-N and preferably below 7 mg/L.
4. Have a Class 2 State certified operator as minimum requirement for operating the plant.

The check valves and block and bleed valves were incorporated into the plant as required by the State of California. Two McFarland Mutual Water Co. employees were certified by the State as Class 2 operators. The plant design includes automatic monitoring for conductivity on the influent and product water and automatic monitoring for nitrate on the product water. Periodic grab samples will also be collected and analyzed manually.

OPERATION

Semi-automatic

McFarland's nitrate removal plant was completed for semi-automatic operation in October, 1983. The plant is now fully automated but the data in this report was collected under semi-automatic operation. The plant has been operating four to eight hours per day using the same sequence of events that will occur under full automation. Under semi-automatic operation, an operator is required to actuate pushbutton switches that start the service and regeneration modes for each vessel and to turn the system off if nitrate or conductivity exceed the limits. The plant has been operating as described in the plant design section of this report. At the present time the three vessels are charged with a three ft depth of resin and the vessels cycle as shown in Figure 4. Figure 4 shows that, for a three ft bed, each vessel is treating 250 bed volumes in 10.6 hours. One of the three vessels changes from the service mode into the regeneration mode every 5.3 hours. This sequence stops when the plant is turned off by the operator or because of low water demand from the community. The cycling sequence for the three vessels resumes when the plant is turned back on.

The operational sequence of events for each vessel is the following:

1. Service
2. Regenerate
3. Slow Rinse
4. Resin Declassification

Figure 5 shows the arrangement of the distribution manifolds within each vessel. Service flow enters the vessel in the downflow direction through distribution pipe no. 3 and exits through manifold no. 5. Manifold no. 5 has holes on the bottom of the spider arms so that flow is collected from the very bottom of the tank to eliminate dead volume. Regeneration flow enters in the downflow direction through distributor no. 1 and exits through manifold no. 5. Slow rinse water enters through distributor no. 1 and exits through manifold no. 5. Resin declassification water enters through either pipe no. 2 or pipe no. 4 and flows out through half of manifold no. 5 in the upflow direction. Manifold no. 5 is split so that pipes 2 and 4 each feed half of the manifold. The best procedure for declassification at the current brine dosage of 1.5 bed volume of 6% sodium chloride is to let water flow in the upflow direction through half of manifold no. 5 for three minutes and then let the bed settle for three minutes. This is done twice for one side of the manifold and once for the other side.

Reason for Resin Declassification

After the resin bed is backflushed and expanded in the conventional manner the resin beads will always settle the same way with the heavier beads ending up at the bottom of the vessel. Therefore, resin

declassification (mixing) is necessary when partial regeneration is used because resin beads at the effluent end of the vessel will remain in the nitrate form after regeneration and cause increased nitrate in the product water when the vessel goes back into service. Partial regeneration is being used at McFarland to reduce salt cost. Figure 6 shows that a considerable reduction in salt usage is accomplished if some nitrate leakage into the treated water can be tolerated. McFarland is operating with a nitrate leakage of 2 to 5 mg/L NO_3-N into the treated water and when this is blended with 30% untreated water (16 mg/L NO_3-N), the nitrate concentration in the final product water ranges from 6.2 to 8.3 mg/L NO_3-N. Figure 7 shows an example of increased nitrate concentration at the beginning of service because the resin was not properly declassified. Figure 8 shows an example of satisfactory resin declassification. The open bars in Figure 8 depict nitrate concentration from the effluent of the ion exchange vessel and the solid bars show nitrate concentrations from samples that were collected 19 inches above the bottom of the resin bed.

PERFORMANCE

A chemical analysis of untreated, treated, and blended product water is given in Table 4. The Table shows that nitrate-N was being reduced from 16 to 2.6 mg/L in the treated water and the blended product water contained 6.6 mg/L NO_3-N. Blended product water was made up of 70% treated and 30% untreated. Chloride concentration in the blended product water increased from 88.2 to 166 mg/L. Sulfate concentration decreased from 120 to 40 mg/L. The U.S. EPA secondary regulation[4] for both chloride and sulfate concentration is 250 mg/L and Table 4 shows that neither of these ions exceed the secondary regulation in the blended product water.

Table 5 shows typical operational data that were collected during a cycle for each vessel. The Table shows that 1.5 liters of 6% brine was used per liter of resin (3610/2407) and 5.55 meq of Cl per meq NO_3^- removed was required for regeneration. The plant would use 2162 lbs. salt/day if operated continuously. This vessel removed 270.07 meq NO_3 per liter of resin during the run. The average nitrate-N removed before breakthrough was 14.33 mg/L and average leakage was 1.67 mg/L NO_3-N.

Results of repeat runs are given in Table 6. These runs were made with two vessels operating in staggered fashion. The system was operating in the semi-automatic mode for a period of four to eight hours per day. The system was turned off when an operator was not present. Each vessel was regenerated after 260 bed volumes of water were treated. One vessel lags the other vessel by 130 bed volumes. Therefore, the treated water nitrate concentration is the average of the nitrate concentration from one vessel and the concentration from the next vessel taken 130 bed volumes earlier.

A typical nitrate breakthrough curve for one vessel is given in Figure 9. Nitrate readings were taken automatically every 15 minutes. Two hundred seventy seven bed volumes of water were treated in order to clearly show nitrate breakthrough. The large peak in the middle of the run represents a nitrate calibration concentration of 10 mg/L NO_3-N. The smaller peaks, which are proportional to the calibration peak, show that the nitrate-N concentration of the treated water from the vessel ranged from 4.3 to 4.7 mg/L until nitrate breakthrough.

PLANT COSTS

Capital costs for McFarland's Plant are summarized in Table 7. Costs are given for two different vessel sizes; 6 ft. diameter X 6 ft. high and 6 ft. diameter x 10 ft. high. The second column gives costs for the plant with three vessels and 10 ft. side height that was built at McFarland. Table 8 gives the detailed capital costs breakdown for the McFarland Plant. Some costs that were necessary for the prototype, such as a Dionex ion chromatograph and control enclosure that houses a small laboratory, may not be necessary for future systems.

Estimated operation and maintenance costs are given in Table 9. The operators cost was estimated to be one hour per day when the plant is fully automatic. Resin replacement and salt costs are the largest constituents of the O & M costs. The total O & M costs from Table 9 were 12.8 cents/1000 gal. Capital costs were 11.4 cents/1000 gal when amortized at 10% over 20 years (Table 10). Therefore, the total cost for this system is 24.2 cents/1000 gal (Table 10). Table 10 also shows a comparison of present consumers water costs in McFarland to the cost of nitrate removal with the new plant.

SUMMARY

A full scale 1 mgd demonstration plant, using ion exchange, for removal of nitrate from well water was built at McFarland, California. The plant has been performing satisfactorily in the semi-automatic mode since October 1983. Full automation of the plant was completed in June 1984. State of California requirements of reducing nitrate levels below 10 mg/L NO_3-N and eliminating brine from the product water have been met. Total costs for the plant, including capital and operation and maintenance were 24.2 cents/1000 gal. Research is continuing at McFarland on nitrate selective resins, regenerant re-use, monitoring and brine disposal, in an effort to further improve the process and reduce costs.

ACKNOWLEDGEMENT

This project is being supported by the McFarland Mutual Water Co. and by grants from the Environmental Protection Agency, the Kern County Community Development Department (HUD), and the Kern County Water Agency.

The authors gratefully acknowledge Ernest Kartinen and Steve Paliska of Boyle Engineering Corp. for the plant design and Carol Hust of the McFarland Mutual Water Co. for his work as project manager.

REFERENCES

1. "National Interim Primary Drinking Water Regulations," Environmental Protection Agency, Office of Water Supply EPA-570/9-76-003 U.S. Govt. Printing Office, Washington, D.C., 1976.

2. Guter, G. A. "Operation, Performance and Cost of the McFarland, CA Nitrate Removal Plant." Proceedings AWWA Seminar on Control of Inorganic Contaminants, Sponsored by The Water Quality Division AWWA. Las Vegas, Nevada, June 1983.

3. Guter, G.A. "Removal of Nitrate from Contaminated Water Supplies for Public Use, Final Report," Municipal Environmental Research Laboratory, Office of Research and Development, U.S. EPA, Cincinnati, Ohio. EPA-600/2-82-042, August 1982.

4. "National Secondary Drinking Water Regulations," Environmental Protection Agency, Office of Drinking Water, EPA-570/9-76-000, Washington, D.C., 1976.

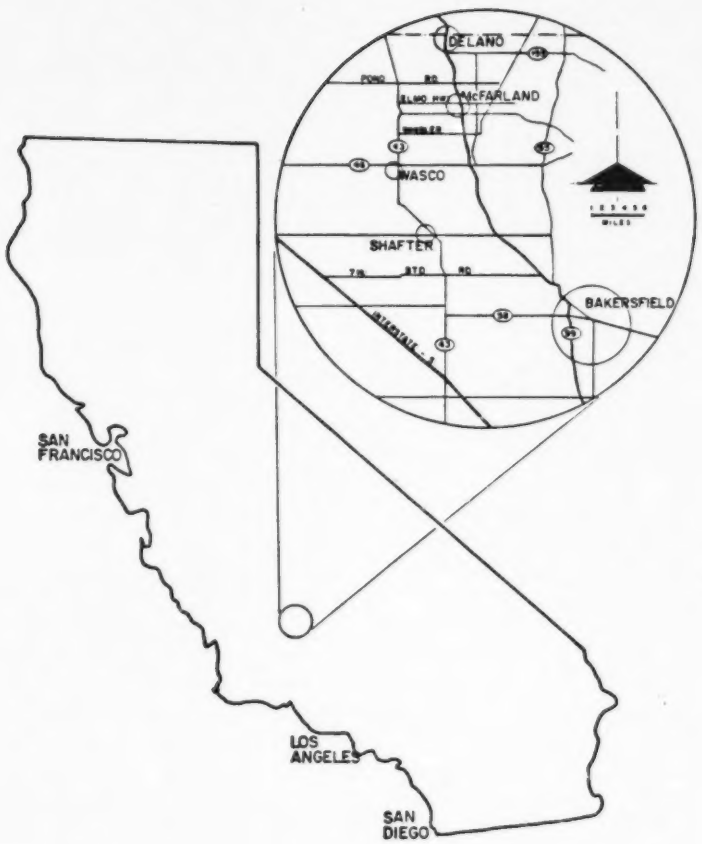
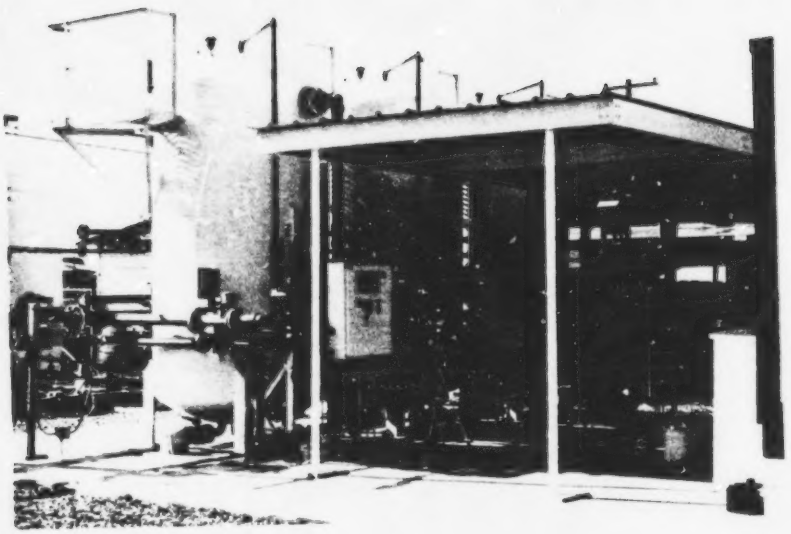


Figure 1. City of McFarland Vicinity Map



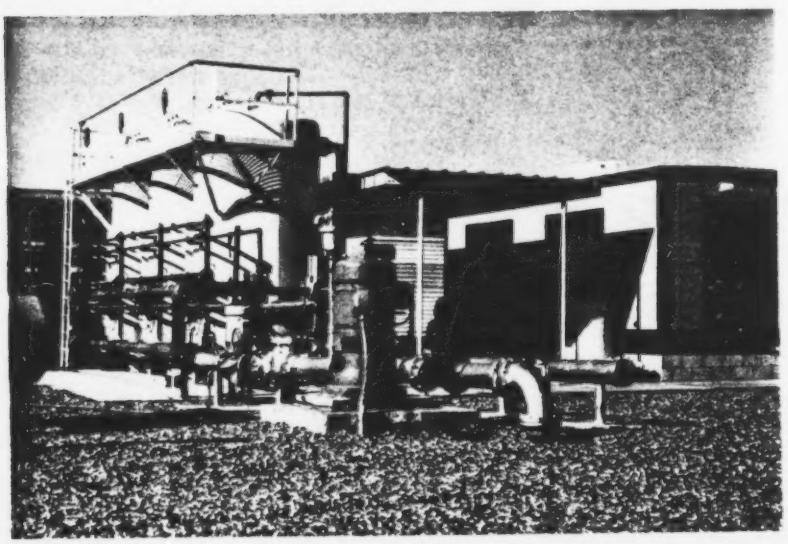


Figure 2. Two Views of Nitrate Removal Plant. Well 2.

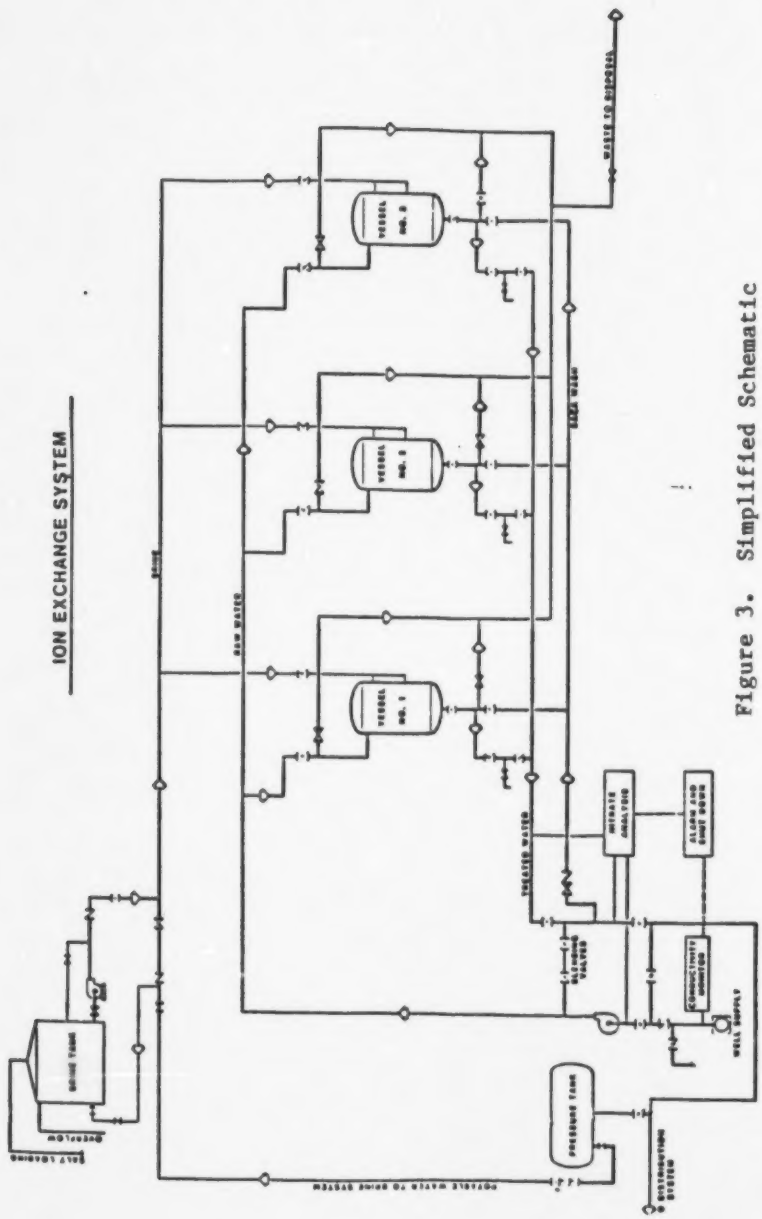


Figure 3. Simplified Schematic

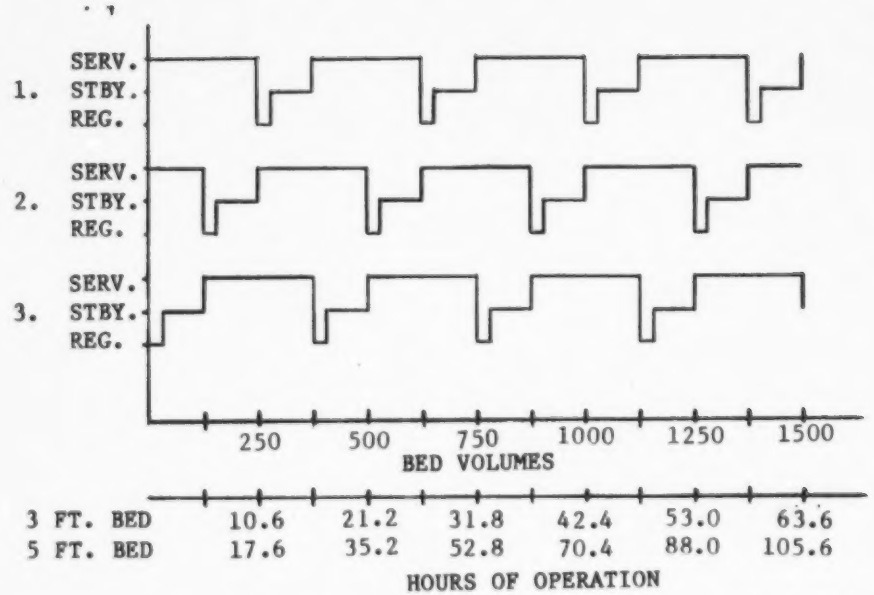


Figure 4. Cyclic Operation of the Three Vessels at 250 gpm/Vessel

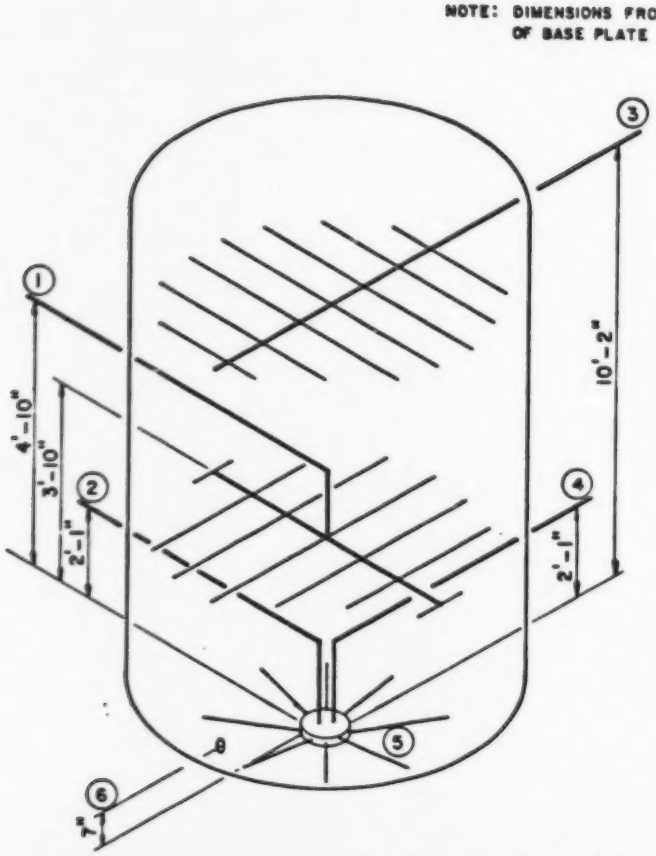


Figure 5. Distributors and Collector Locations

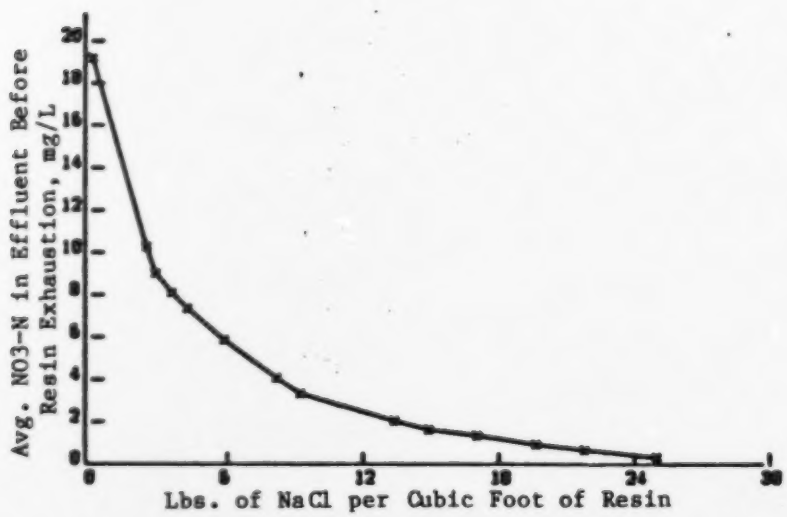


Figure 6. Pilot Column Ion Exchange System Nitrate Leakage Dependence on Salt Loading

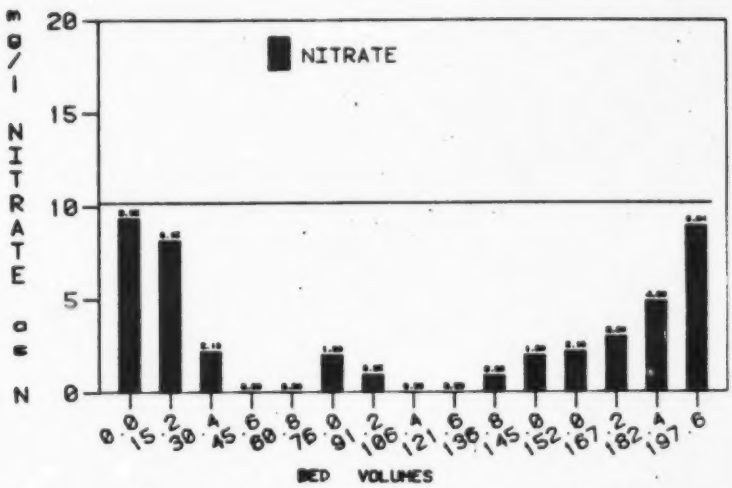


Figure 7. Resin Declassification Tests

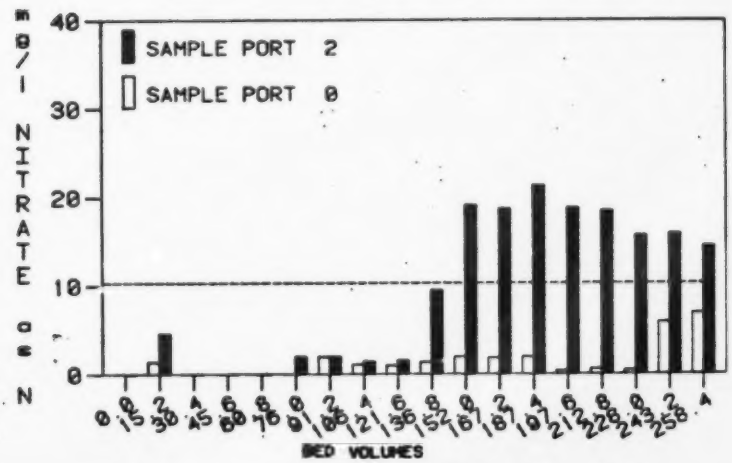


Figure 8. Resin Declassification Tests

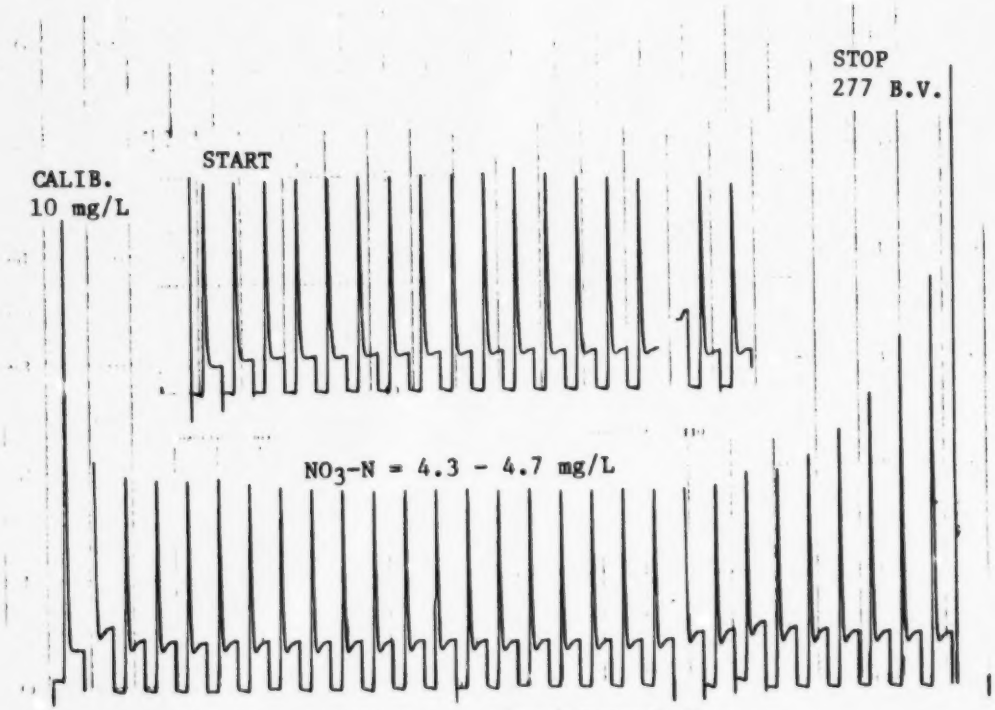


Figure 9. Typical NO_3 Breakthrough Curve

TABLE 1. COMPOSITION OF McFARLAND WELL WATER (MG/L)

Well No.	1	2	3	4
Date	5-8-80	4-9-80	5-1-80	4-1-80
Calcium	28	88	156	78
Sodium	50	65	100	72
Bicarbonate	88	102	121	95
Chloride	28	86	94	51
Sulfate	51	105*	310	182
Nitrate-N	6.8	15.1*	22.1	10.6
TDS	235	466	827	485
pH units	7.7	7.2	7.3	7.7

* Analyses on 5-31-78 gave sulfate = 261 and nitrate = 17.6

TABLE 2. BED CHARACTERISTICS & TARGET FLOWS (3 FT. BED)

Bed cross sec. area	= 27.7 sq. ft.
Bed depth	= 3 ft.
Bed volume	= 85 cu. ft., 635.8 gals
Approx. sat. brine con.	= 2.6 lbs/gal.
Saturated brine rate	= 12 gpm
Brine rinse duration	= 15 min.
Diluted brine rate	= 63.5 gpm
BV of 6% brine at above parameters	= 1.5
Slow rinse rate	= 64 gpm
Slow rinse duration	= 30 to 50 min.
Declassification rate	= 5 gpm/sq. ft. = 140 gpm

PRESENT OPERATING CONDITIONS

Total product water	= 700 gpm
Quantity treated	= 500 gpm
Quantity treated/vessel	= 250 gpm
BV treated/regeneration	= 250
Salt use (500 gpm, continuous)	= 2162 lbs/day
Service loading rate (250 gpm)	= 9.03 gpm/sq. ft.
Contact time	= 2.54 min.
Nitrate-N influent	= 16 mg/L
Nitrate-N product	= 6.2 to 8.3 mg/L

TABLE 3. FREQUENCY OF REGENERATION FOR 3. FT AND 5 FT. OF RESIN

Bed Volumes Treated	Percent of Full Capacity					
	100%		70%		50%	
	bed depth (ft.)		bed depth (ft.)		bed depth (ft.)	
	3	5	3	5	3	5
	No. of Regenerations per Vessel per Day					
200	2.62	1.57	1.83	1.10	1.31	0.79
250	2.10	1.26	1.47*	0.88	1.05	0.63
300	1.75	1.05	1.23	0.74	0.88	0.53
400	1.31	0.79	0.92	0.55	0.66	0.40

* Present operating condition

TABLE 4. CHEMICAL ANALYSIS OF UNTREATED, TREATED AND BLENDED WATER

Constituent	Untreated	Treated	Blended
Calcium (mg/L)	94	98	96
Magnesium (mg/L)	2.1	2.1	2.1
Sodium (mg/L)	68	68	68
Potassium (mg/L)	3.8	3.6	3.8
Bicarbonate (mg/L)	119	27.7	120
Chloride (mg/L)	88.2	264	166
Sulfate (mg/L)	120	less than 5	40
Nitrate-N (mg/L)	16	2.6	6.6
Color units	1	1	1
Odor	none	none	none
pH units	7.2	7.4	7.4
EC, micromhos/cm	790	920	850

TABLE 5. OPERATIONAL DATA FOR ONE CYCLE OF ONE VESSEL

label of data	run data in	bed vols	Nitrate-Nitrogen Port 0	Nitrate-Nitrogen Port 2	calc'd parameter	calc'd value
Run no.	=11093-p3	000.0	000.0	000.0	meq NO3 removed per liter resin	= 270.07
	========	0.0	0.0	0.0		========
Resin	=A 101D	0.0	0.0	0.0		
	========	15.2	1.4	4.56		
Well no.	=2	30.4	0.0	0.0		
Liters of resin		45.6	0.0	0.0		
		60.8	0.0	0.0	meq Cl used per liter resin	=1499.79
		76.0	0.0	1.99		========
	=2407	91.2	1.99	1.99		
	========	106.4	1.13	1.45		
Liters of 6% brine		121.6	0.99	1.58		
		136.8	1.4	9.53		
	=3610	152.0	1.99	19.08		
	========	167.2	1.9	18.67	meq Cl used per meq NO3 removed	= 5.55
NO3 mg/L in		187.4	1.99	21.27		========
	=16.0	197.6	0.41	18.79		
	========	212.8	0.59	18.47		
SO4 mg/L in		228.0	0.45	15.69		
	=120	243.2	5.96	15.9		
	========	258.4	6.95	14.5		
		259.4	10.16	14.5	BV(N)	= 259.4
Cl mg/L in						========
	=88.2					
	=========					
HCO3 mg/L in						
	=119				meq SO4	= 2.50
	=========					========
No of brine fractions					meq NO3	= 1.14
						========
	=partial				meq S+N	= 3.64
	========					========
=========					per liter influent	
Run format					NO3 removed ppm (average before bkth)	= 14.33
						========
					NO3 leakage ppm (average before bkth)	= 1.67
						========

TABLE 6. NITRATE-NITROGEN CONCENTRATIONS FOR REPEAT RUNS AT GIVEN NO. OF BED VOLUMES TREATED.

Brine Gal. 6%	Date 1984	Unit	Bed volumes treated						
			0	91	182	212	228	242	260
			NO_3 - N conc. mg/L						
991	4-24	1	2.0	2.7	2.7	5.2	6.8	6.8	7.2
954	4-26	2	2.3	1.1	2.7	3.4	8.6	9.0	9.5
1245	4-26	3	0.7	1.4	9.9	8.8	8.8	8.8	8.8
970	4-27	1	2.3	2.5	4.3	4.7	5.0	5.6	6.8
1176	4-30	2	3.2	2.3	4.3	5.0	4.7	5.0	6.8
938	5-1	3	1.6	2.3	4.3	4.3	5.2	6.1	7.0
842	5-2	1	3.4	5.0	4.5	3.8	5.4	6.8	7.5
927	5-3	2	5.4	5.6	2.9	4.1	5.2	6.1	6.3
901	5-4	3	2.9	2.0	4.7	5.4	5.4	6.3	7.2
895	5-7	1	2.5	2.3	3.2	4.1	5.2	5.4	5.6
869	5-9	2	3.4	2.0	4.5	5.2	5.0	5.4	5.6
779	5-9	3	4.1	2.3	3.6	5.4	6.1	7.7	7.9
1028	5-11	1	4.3	2.3	2.9	6.3	5.6	6.1	6.3
938	5-11	2	2.0	2.5	5.4	6.1	6.3	6.1	5.9
938	5-15	3	4.5	2.3	3.4	3.6	3.8	4.5	5.0
1001*	5-16	1	2.0	2.7	2.7	3.2	3.4	3.8	5.0
885*	5-17	2	2.9	2.5	2.7	2.9	3.2	3.2	3.8
938*	5-18	3	3.6	3.4	2.7	3.6	3.8	4.5	5.6

†Influent NO_3 - N = 16 mg/L

*Using T1-500

TABLE 7. CAPITAL COSTS, MCFARLAND (1983)

Item	Vessel Size 6'D x 6'H	6'D x 10H*
I.X. Vessels (3 included)	$ 96,511	$111,741
On-site construction	81,151	81,154
Brine tank	18,700	18,700
Other	40,045	40,045
Resin 225 cu. ft. (3 ft. depth)	35,000	
424 cu. ft. (5 ft. depth)		56,610
Sub total	$271,407	$309,250
Engineering & administration 15%	40,711	46,388
Total	$311,118	$355,638

* McFarland's plant

TABLE 8. COST DETAIL FOR EQUIPMENT AND CONSTRUCTION

3 Ion exchange vessels 6'D x 6'H	$ 96,511
+ 4 ft. added H	8,375
+ walkway and ladder	6,855
Sub total ion exchange vessels	$ 111,741
Sewer, catch basin	$ 6,156
Electricial and sample conduits	2,166
Concrete pads	6,400
Booster pump	3,651
Brine pump	1,227
Air compressor	2,073
Steel piping	13,900
Flow, conductivity meters	15,795
PVC piping	4,667
Above gr. electrical	20,603
Set I.X. unites, connect	1,448
Set brine tank	868
Miscellaneous	2,200
Sub total on-site construction	$ 81,154
Brine tank	$ 17,527
Delivery	1,173
Sub total brine tank	$ 18,700
Other	
Control panel	$ 7,614
Dionex	12,455
Control enclosure	9,833
Programmable controller	10,143
Sub total other	$ 40,045

TABLE 9. OPERATION AND MAINTENANCE COSTS

Item	Annual costs($)	$/1000 gal.
Operation (1 hr/day)	4,745	0.013
Normal O&M, 2X(355,638)	7,113	0.019
Power, boost pump (.093/kwh)	8,140	0.022
Resin replacement (5 yrs)	11,522	0.032
Salt ($31.50/ton), 70% cap.	12,429	0.034
Miscellaneous	3,000	0.008
TOTAL O&M	46,949	0.128

TABLE 10. TOTAL COST OF PLANT AND COMPARISON TO PRESENT WATER COST IN McFARLAND

Total Costs (Capital + O&M)

	Annual Costs($)	$/1000 gals.
Capital costs - $355,638 (20 yrs. 10%)	41,773	0.114
Operation & maintenance	46,949	0.128
TOTAL	88,722	0.242

PRESENT COSTS OF WATER IN MCFARLAND

	$/1000 gals
First 11,000 gals.	0.980
Over 11,000 gals	0.468